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Alternative Analysis of Selorejo Reservoir Sediment Control for Maintenance Cost Efficiency

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***Abstract*— *The Selorejo Dam, which was completed in 1970, has experienced a high decline in storage capacity due to sedimentation rates from the upstream Konto river watershed. The maximum reservoir capacity in 1970 was 62.3 million m3 in 2017 to 30.72 million m3. Reservoir maintenance activities, in this case technical sediment control, have not been able to recover or maintain reservoir storage capacity, so alternative reservoir sediment control is needed that is able to maintain reservoir service life and is economically efficient. This research was conducted to analyze the effectiveness and efficiency of sediment control technically from 5 (five) alternatives proposed to be implemented in the Selorejo reservoir. The things considered in the alternative are sediment control volume and method, first according to the last condition carried out by reservoir organizer, next is addition of sediment control volume, and combination of sediment control with reservoir sediment dredging method, sabo dam sediment dredging and establishment check dams. Of the five alternatives proposed in controlling sediment, the 1st alternative with sediment dredging volume of 215 m^3 per year resulted reservoir service level 5.62 years, B/C value 1.337 and B-C IDR 40,489,313,011.-, while the 5th alternative with a sediment control volume of 430 m^3 per year resulted in a reservoir service level 11.92 years, B/C value 1.090 and B-C IDR 23,316,604,758.-. In implementing the Selorejo reservoir sediment, these 2 alternatives are effective and efficient compared to the alternatives offered.*

***Keywords*— *Sediment Control, Selorejo Reservoir, Cost Efficiency.*

I. INTRODUCTION

The sustainability of the reservoir in carrying out its main function is determined by the age of the reservoir, its how long the volume of the dead reservoir will be filled with sediment material deposits. The Selorejo Reservoir functions as a flood control Q_{1000} max of 920 m^3/sec controlled to 360 m^3/sec, Q_{200} flood control of 680 m^3/second is controlled to 260 m^3/second, a power plant with 4,500 kW power and an additional discharge in the dry season of 4 m^3/sec in the Pare & Jombang irrigation area. The maximum reservoir capacity in 1970 was 62.3 million m^3 and in 2017 it was 30.72 million m^3 (reduced by 50.69%). Periodically, since 2001 Jasa Tirta I Public Corporation (PJT I) dredged reservoir sediments using dredges with reservoir dredging capacity varying from 50,000 m^3 to 300,000 m^3 per year. There are limitations to dredging reservoirs: the range of dredger cutter section ladder is limited to effective storage and disposal area/spoilbank capacity has decreased. Other technical efforts to control reservoir sedimentation with sediment control structures are sabo dams or check dams. Sediment control activities carried out to date have not been able to restore or maintain reservoir storage capacity so research is needed to determine the appropriate sediment control methods so that sediment control efforts can maintain the function of reservoir benefits while being economically feasible.

II. OBJECTIVES

This paper will discuss sedimentation conditions in the Selorejo reservoir and to find out the effective and economically efficient alternatives in the context of reservoir sediment control

III. RESEARCH METHODOLOGY

A. Study Area

This study was conducted at the Selorejo reservoir in the Konto river basin. The Selorejo reservoir is surrounded by mountains Kelud, Kawi and Anjasmoro, receiving water from three rivers: the Konto, Pinjal and Kwayangan. Konto watershed with an area of 23,625 ha. Geographically, the Konto sub-watershed itself is located between 11203 '45.89 "East, 7030' 8,234" South Latitude and 112030 '1,716 "East, 7057' 22,423" South Latitude.

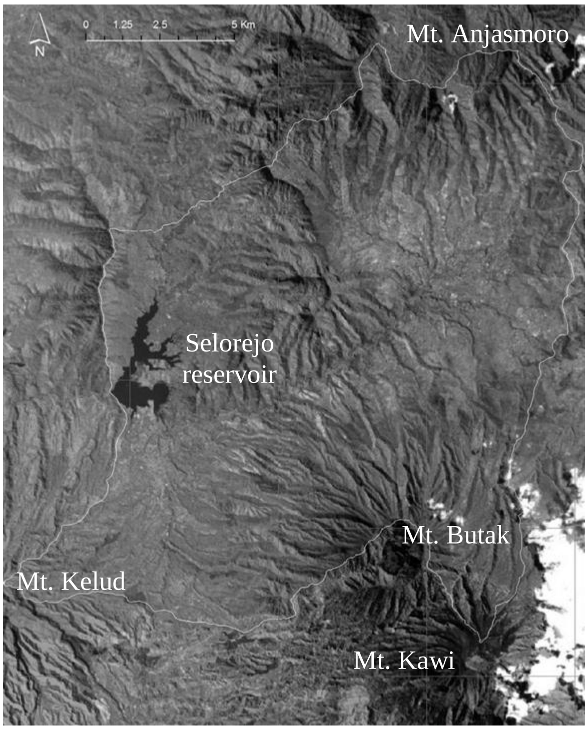

Fig. 1. Map the upstream Selorejo reservoir.

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B. Data Types and Sources

The type of data used in this study is secondary data from related research and measurement data carried out including erosion data and sedimentation rates, reservoir bathimetry measurements, spoilbank capacity zones and capacities, sediment control building (sabo dam and checkdam) data, and sediment material data.

C. Watershed Erosion Analysis

The erosion process consists of three sequential parts: detachment, transportation, and sedimentation [1]. Factors that cause erosion are erosion factors expressed in erosivity and soil factors expressed in erodibility, namely: climate/rainfall (R), soil type (K), topography (LS), vegetation (C) and management land (P) [2]. Watershed erosion analysis is done by calculating the percentage level of erosion in contributing to the sedimentation rate of tributaries that are dammed by the Selorejo reservoir, from Konto river, Kwayangan river and Pinjal river.

D. Reservoir Sedimentation Conditions Analysis

Analysis is carried out to determine reservoir characteristics and current reservoir conditions due to sedimentation that occurs using data from the measurement of reservoir storage capacity that is routinely carried out. From this analysis we will find changes in storage conditions, trap efficiency, volume, sedimentation rate and age of reservoir service remaining.

The storage of a reservoir consists of dead storage, effective storage and flood storage. Effective storage are often also called active storage, because these reservoirs always fluctuate depending on the inflow and outflow of the reservoir to meet needs.

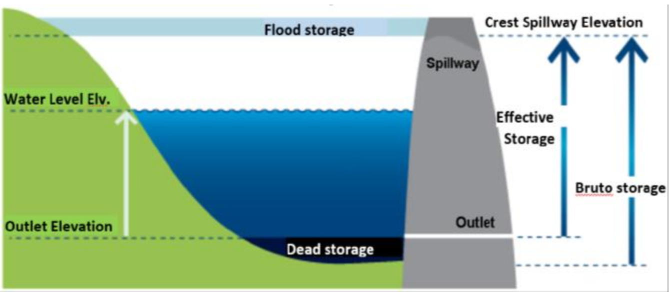

Fig. 2. Sketch of Dam reservoir.

The service life limit of a reservoir is a period or number of years from the start of operation of the reservoir until the reservoir functions are exhausted to be able to regulate output water through intake. Determined by the length of time the dead storage volume is filled by sediment.

From the measurement of sediment collected in the reservoir it can be seen the change in sedimentation rate. To estimate how many years more the amount of sedimentation exceeds the dead storage can be used a linear regression equation, by finding the relationship between the age of use and the amount of sediment.

Linear regression is one of the types of forecasting or prediction analysis that is often used on quantitative scale data (intervals or ratios) [3].

$$Y = A + BX$$
$$A = (\sum Y - B.\sum X)/n$$
$$B = (n\sum X.Y-\sum X.\sum Y)/(n\sum X^2-(\sum X)^2)$$

with:

X : service life

Y : cumulative sediment volume (million m^3)

n : amount of data

In a simpler way, calculation of reservoir service age can be calculated based on reservoir sedimentation rates per year against the amount of the volume of the dead storage with the following formula [4]:

$$T = V/Lj$$

with:

T : Age of reservoir (year)

V : Reservoir dead capacity (m^3)

Lj : Sediment rate (m^3/year)

In determining the age of a dam plan, it is not only necessary to know how much sediment material and type are entering, but also how much sediment will be deposited. The ability of the reservoir to hold and deposit the sediment is called trap efficiency, which is expressed as a percent of the amount of sediment carried by the inflow.

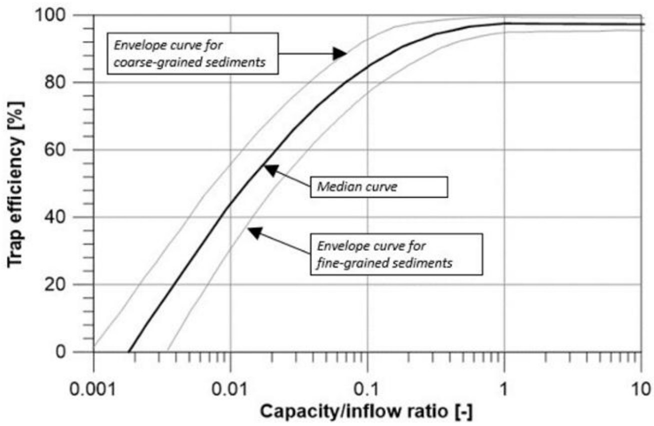

Fig. 3. Efficiency Trap Curve.

The efficiency of this reservoir depends on the nature of the sediment and the discharge entering the reservoir. The relationship between reservoir efficiency and the ratio between reservoir storage capacity and annual discharge entering the reservoir are formulated [5] as follows:

$$Y = 100\,(1 - 1/(1+ax))n$$

with:

Y : Storage efficiency

x : Comparison of reservoir storage capacity with annual inflow

a : constants, i.e.: a = 100 for the average curve
a = 65 for the minimum curve
a = 130 for the sheath curve

n : constants, i.e.: n = 1,5 for the average curve
n = 2,0 for the minimum curve
n = 1,0 for the sheath curve

E. Alternative Analysis of Reservoir Sedimentation Control

Reservoir sedimentation control can generally be divided into three types of activities or businesses [6]:

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1. Pressing the rate of erosion upstream. Actions to suppress erosion rates in the upstream area can be done structurally (treating civil and vegetation), or non-structural (social) measures.
2. Minimizing the burden of sediment entering the reservoir. Reducing the burden of sediments entering the reservoir can be done in two ways, by catching sediment through a basin channel system (sabo dam/check dam), and diversion of sediment that will enter the reservoir to other areas outside the reservoir (sand bypass).
3. Removing sediment deposits in reservoirs. Removing sediment out of the reservoir is the last effort that must be implemented. Two ways that are often taken are by flushing through the bottom outlet output facilities, as well as dredging

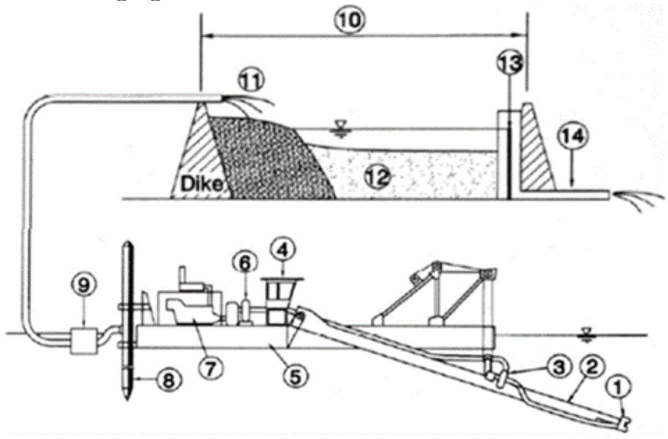

Fig. 4. Schematic diagram of a hydraulic dredger and disposal area.

Reservoir Dredging Process

Four basic components consideration for reservoir dredging covering: 1) sediment to be dredged (dredging location), 2) equipment for dredging, 3) equipment for channeling dredged material such as pipes for dredging hydraulic, and 4) location of dredging material (riverine disposal to the river downstream of the dam or off-stream disposal/spoil bank) [6].

Sediment Control Building

In its application in Indonesia, sabo dam/check dam means a building to hold material from landslides and control material flooding or cold lava flooding. Sabo dam is a type of sediment control building that is usually built in the upstream area. The full Sabo dam still has the ability to temporarily accumulate a number of sediments. These sediment deposits are on the surface of dead storage and are referred to as volume control

Alternative sediment control reservoirs are planned with two (2) conditions, firstly carried out in accordance with the latest sediment control conditions that have been carried out by reservoir organizer and secondly carried out by adding sediment control volumes and a combination of sediment control methods.

F. *Sediment Control Costs Analysis*

Dam/reservoir maintenance activities are activities required to maintain dam/reservoir functions including dredging of sediment reservoirs, repairing canals, constructing sediment control structures and dredging. The amount of the fee depends on the capacity, reservoir life, problems and methods of maintenance and or repairs carried out. Costs are incurred over and over again and are required to operate and maintain the item in question for its useful life [7].

From each of the alternative sediment control costs will be calculated. The unit price value is calculated from the value of salary, material and equipment prices

G. *Steps for Cost Benefit Analysis (CBA) Economic Analysis*

Project Alternative Identification

The main purpose of CBA is to find the most appropriate sediment management project, among several project alternatives.

Identification of Costs and Benefits

Project costs and project benefits are the main elements in CBA. the identification of cost and benefit elements depends on the perspective of the organization in the project.

Net Present Value (NPV)

Method of calculating net value at the present time. The present assumption is to explain the initial time of the calculation to coincide with the time of the evaluation or in the zero year period (0) in the cash flow calculation. The NPV method basically transfers cash flow that spreads throughout the life of the project to the initial investment time or present condition. Generally, PV can be calculated using the following formula [8]:

PV=FV/(1+i)n

Parameter Analysis

CBA uses three (3) economic parameters to analyze projects, which include the Benefit Cost Ratio (B/C ratio), Net Benefit (B-C) and Internal Rate Return (IRR). In this study, the parameters used are limited to B/C Ratio and B-C.

B/C Ratio provides a value comparison between the benefits (benefits) obtained with aspects of costs and losses to be borne (cost). If the B/C ratio does not exceed 1.0, the project is considered unfeasible. If it is exactly 1.0, it is considered a marginal project, and if it exceeds 1.0, then the project is feasible.

B/C Ratio = ∑benefits / ∑costs

Net Benefit is defined as a reduction of all profits to the sum of all costs. Projects with higher net benefits are considered the most economical projects.

Net Benefits = ∑benefits -∑ costs

IV. Result And Discussion

A. *Selorejo Reservoir Sedimentation Rate Analysis*

The results of erosion transported to the Kali Konto flow through its tributaries finally settled in the Selorejo reservoir. It is the main cause of sedimentation problems in the Selorejo reservoir.

The measurement of the reservoir volume of the Selorejo is h periodically starting at the beginning of the inundation of the reservoir in 1970 until the measurement in 2019. The method used in the measurement is echo sounding of the

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reservoir, the result of which is the contour map of the Selorejo Echosounding Reservoir.

Fig. 5. Condition of Selorejo reservoir sedimentation

Based on the results of the 2019 echo sounding measurements, the total storage capacity was 31.81 million m^3, the effective storage capacity was 31.28 million m^3 and the dead storage capacity was 0.53 million m^3. Compared to the initial conditions in 1970, the effective storage volume was reduced by 18.82 million m^3.

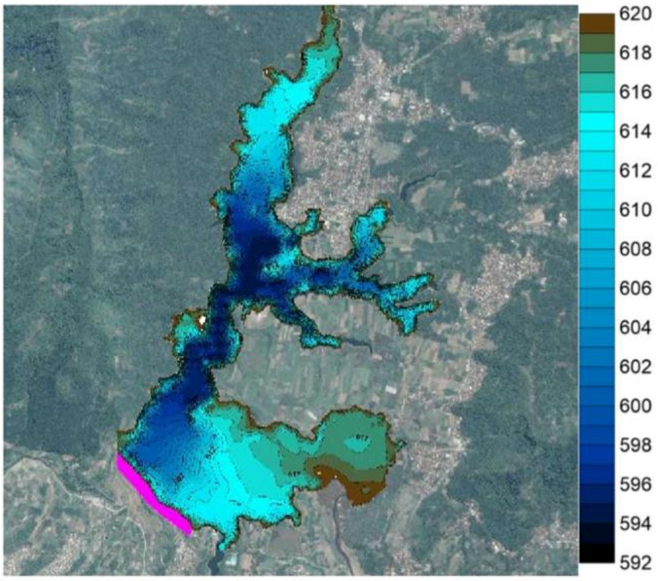

Fig. 6. Map of the Selorejo reservoir echosounding 2019

The condition of the reservoir capacity of the Selorejo Reservoir from 1970 and 2019 can be seen in Table 1 and the periodic changes with the curved capacity presented in Figure 7. Selorejo reservoir sediment profile measurement results in 2019 are shown as in Figure 8.

TABLE 1. Selorejo reservoir volume from echosounding measurement

Elevation (m)	Reservoir Volume (juta m^3)			Sediment Volume
	Th 1970	Th 2019	(%)	(milion m^3)
HWL = + 622,00	62,30	31,81	51,06	30,49
LWL = + 598,00	12,20	0,54	4,43	11,66
Efektif Volume	50,10	31,27	62,42	18,83

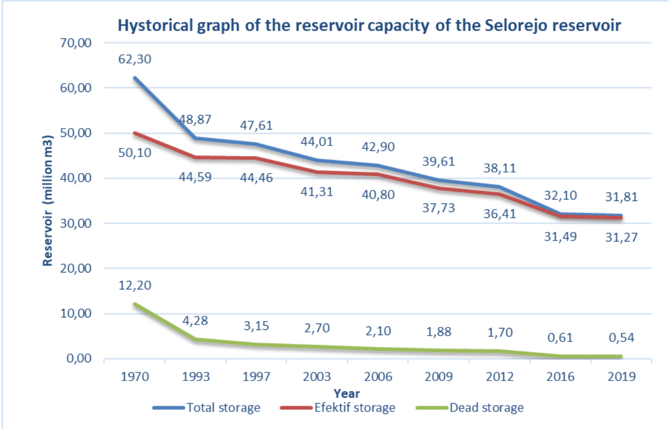

Fig. 7. Changing capacity of Selorejo reservoir reservoir

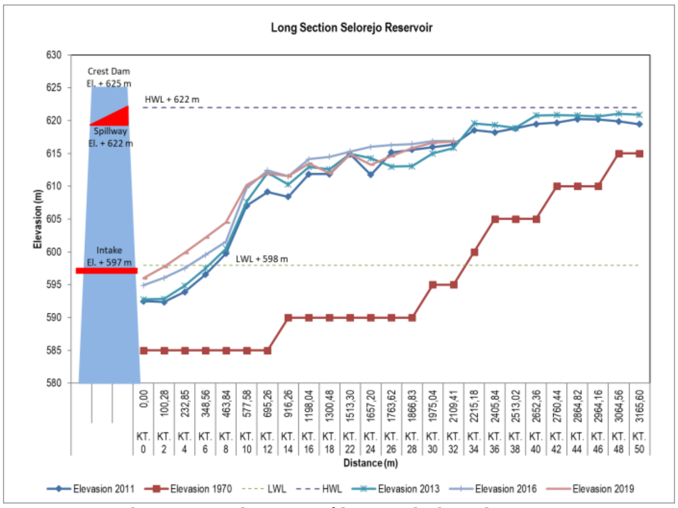

Fig. 8. Changes in sediment profile extends the Selorejo Reservoir

The calculations using discard data for 1993, 1997, 2003, 2006, 2007, 2009, 2011, 2012, 2013, 2014, 2016, 2017, 2018 and 2019, the constants a and n are the values for the average curve, i.e. a = 100 and n = 1.5 results of the Selorejo reservoir efficiency trap in table 2 shows a declining trend. This is proportional to the reduction in reservoir storage capacity to accommodate sediment.

TABLE 2. Calculation of trap efficiency the Selorejo reservoir

Year	a	n	Reservoir capacity (million m3)	Annual Inflow (million m3)	x	Trap Efficiency (%)
1970	100	1,5	62,30	347,850	0,179	92,17
1993	100	1,5	48,87	350,127	0,140	90,14
1997	100	1,5	47,61	259,237	0,184	92,36
2003	100	1,5	44,01	264,966	0,166	91,60
2006	100	1,5	42,90	300,850	0,143	90,33
2007	100	1,5	41,69	313,581	0,133	89,69
2009	100	1,5	39,61	361,111	0,110	87,73
2011	100	1,5	38,25	537,571	0,071	82,10
2012	100	1,5	38,11	365,877	0,104	87,15
2013	100	1,5	36,57	428,117	0,085	84,70
2014	100	1,5	34,82	389,471	0,089	85,30
2016	100	1,5	32,10	381,368	0,084	84,50
2017	100	1,5	31,64	411,540	0,077	83,24
2018	100	1,5	31,27	377,990	0,083	84,27
2019	100	1,5	31,81	318,685	0,100	86,66

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B. Reservoir Service Age Remaining Analysis

From the calculation of linear regression with the help of MS. Excel shown as in Figure 9 obtained the regression equation as follows:

$Y = 0.1258\ X + 5.3524$

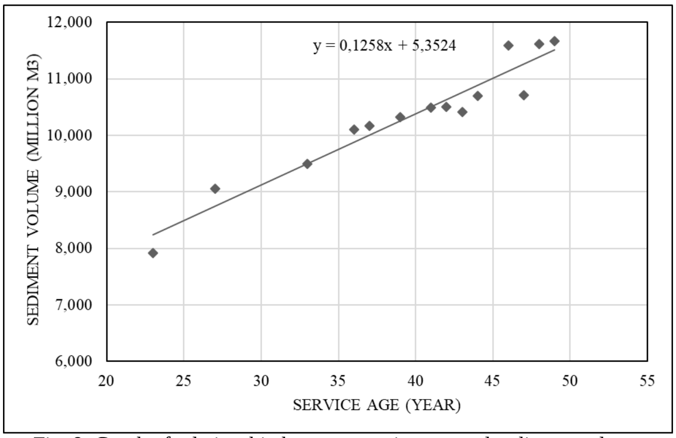

Fig. 9. Graph of relationship between service age and sediment volume

By entering the planned reservoir reservoir dead capacity of 12.2 million m^3, it can be concluded that the service life of the Selorejo reservoir is based on the actual sedimentation rate deposited in the reservoir and sediment control activities that have been carried out up to 2019 are 54.43 years or up to 2023.

C. Selorejo Reservoir Sedimentation Control Analysis

From the accumulation of reservoir dredging up to 2019 if it is reviewed since the completion of reservoir construction (1970) it can be seen that the work of dredging Selorejo reservoir sediment in reducing the average sedimentation rate per year is 49.518 m^3/year.

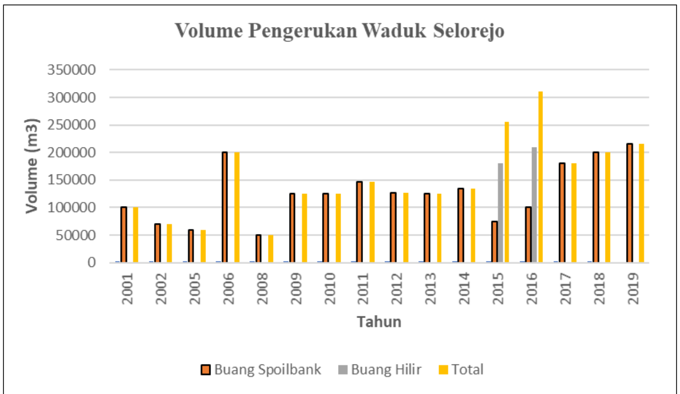

Fig. 10. Graph of Selorejo reservoir dredging volume

Upstream of the Selorejo reservoir, a number of sabo dams and check dams have been built, both from the river stone pair and from the gabion. Currently some sediment control structures whose construction is still in good condition are full of sediment storage, while others (some of gabions check dam) are in a damaged condition. So that sediments coming from upstream will enter the waters of the Selorejo reservoir.

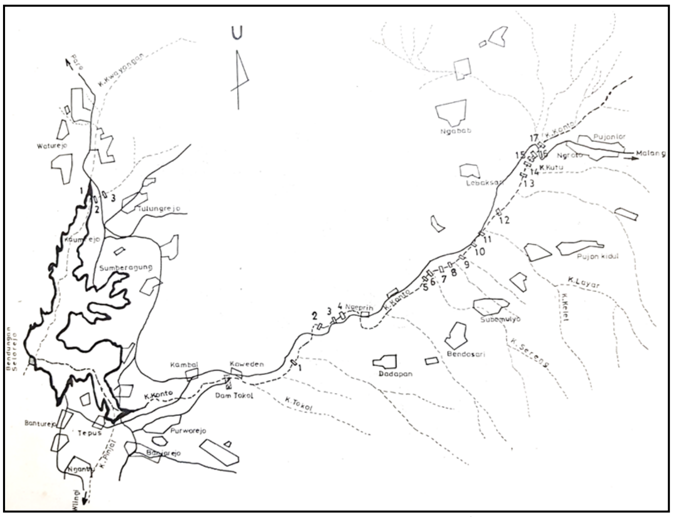

Fig. 11. Sabo dam layout and check dam upstream of the Selorejo reservoir

Proposed sediment control methods are technical control with a combination of reservoir sediment dredging methods, sabo dam dredging and check dam construction with the volume of alternative sediment control activities of 215,000 m^3 and 430,000 m^3. It can be calculated that the addition of reservoir service life for the two alternatives is as follows:

Alt. 1 = dead storage capacity in 2019 / (average sediment rate that occurs x percentage of sedimentation in dead storage)

= 540,000 m3 / ((622,000 - 215,000) x 23,592%) m^3

= 5.62 years since the last measurement (2019)

Alt. 2 = dead storage capacity in 2019 / (average rate of sediment occurring x percentage of sedimentation in dead storage)

= 540,000 m3 / ((622,000 - 430,000) x 23,592%) m3

= 11.92 years since the last measurement (2019)

TABLE 3. Alternative matrix of reservoir sediment control

Alt.	Sediment control volume (m^3)	Dredging reseroir sediment				Dredging sabo dam deposit sediment	Check dam construction	Information
		Sp.bank volume by exaltation existing s.b. (m^3)	New sp.bank volume (m^3)	Sp.bank volume by hauling existing s.b. (m^3)	Riverine disposal (down stream) volume (m^3)	Sediment volume (m^3)	Sediment volume accommoda-ted (m^3)	
1	215.000	130.000		85.000				
2	430.000	130.000	250.000	50.000				
3	430.000	130.000	250.000		50.000	50.000		Dredging in sabo dam di Mendalan S.D.
4	430.000	130.000	250.000				50.000	
5	430.000	130.000	250.000			50.000		Dredging in sabo dam di Tokol S.D.

The cost calculation is carried out by multiplying the unit price of the work by each alternative volume of sediment control work. The recapitulation of sediment control volumes and costs for each alternative is shown in table 4.

TABLE 4. Recapitulation of sediment control costs in the first year

No.	Description	Unit Price (Rp)	Alternative Cost of Sediment Control (Rp x 1000)				
			Alternatif 1	Alternatif 2	Alternatif 3	Alternatif 4	Alternatif 5
1	Dredging cost						
	- with existing equipment dispose of downstream	37.000			1.850.000		
	- with existing equipment dispose of spoilbank	40.000	8.600.000	8.600.000	8.600.000	8.600.000	8.600.000
	- with additional equipment dispose of spoilbank	52.000		11.180.000	8.580.000	8.580.000	8.580.000
2	Spoilbank cost						
	- exaltation eksisting spoilbank	18.000	2.340.000	2.340.000	2.340.000	2.340.000	2.340.000
	- land acquisition + new spoilbank	48.000		12.000.000	12.000.000	12.000.000	12.000.000
3	Spoilbank hauling cost	58.000	4.930.000	2.900.000			
4	Sabo dam dredging cost	55.000			2.750.000		2.750.000
5	Check dam construction cost	218.000				10.900.000	
	Total		15.870.000	37.020.000	36.120.000	42.420.000	34.270.000

D. Benefits Analysis

In the analysis of the benefits of electricity production after sediment control is used the average electricity production volume in the last 10 years. With the water resource management service costs (BJPSDA) hydropower plant (PLTA) tariff of IDR 167 /kWh, the economic value of the Selorejo hydropower is IDR 4,651,821 million/year, the Mendalan hydropower IDR 12,883,768 million/year and the Siman hydropower plant of IDR 9,393,918 million/year with a total of 3 (three) hydropower plants in the amount of IDR 26,929.507 million/year.

The economic value of water for irrigation purposes is calculated based on the BJPSDA value for Brantas river area irrigation which is IDR 824,741 /ha [9], so that the total benefits for irrigation donated by the Selorejo reservoir are IDR 4,701,024 million/year.

Flood control (in the downstream area of Konto river) is a maximum flood (1000 years) of 920 m^3/sec can be controlled to 360 m^3/sec. And 200-year floods of 680 m^3/sec can be controlled to 260 m^3/sec. Damage that can be avoided due to flooding is IDR 1,500,000,000/year [10].

E. Economic Analysis

The assumptions used in economic analysis include the interest rate is 9.95% and the inflation rate is 2.96%. The interest rate is used to determine the present value of costs and benefits while the inflation rate is used to determine the value of the increase in costs and benefits per year. From the results of economic analysis, by controlling sediment for 10 years, B/C and B-C parameters of each alternative are shown as shown in table 5.

TABLE 5. Results of sediment control alternative economic analyzes

Economic Parameter	Control Sediment Alternatif (Rp x 1000)				
	Alternatif 1	Alternatif 2	Alternatif 3	Alternatif 4	Alternatif 5
Total Cost (Rp)	120.154.802	280.285.493	273.471.421	321.169.925	259.464.718
Total Benefits (Rp)	160.644.115	282.781.322	282.781.322	282.781.322	282.781.322
Benefit Cost Ratio (B/C)	1,336976236	1,008904597	1,034043416	0,880472611	1,08986426
Net Benefit (B – C)	40.489.313	2.495.829	9.309.901	(38.388.602)	23.316.604
Additional service age	5,62 year	11,92 year	11,92 year	11,92 year	11,92 year

F. Efficiency and Effectiveness of Alternative Sediment Control Analysis

From the results of economic analysis using the parameters B/C and B-C, alternatives 1, 2, 3, and 5 show the value of B/C> 1 and B-C is positive so it is feasible to be implemented with alternative 1 giving the value of B/C and B-C is the highest or most economically efficient of the 5 alternatives. Based on the calculation of reservoir service age, alternative 1 adds reservoir service age by 5.62 years while alternatives 2, 3, 4 and 5 together add reservoir service age by 11.92 years, with the same additional service age as alternatives 2, 3 and 4, alternative 5 is the most economically efficient compared to alternatives 2, 3 and 4.

V. CONCLUSIONS

The reservoir capacity of the Selorejo reservoir in 2019 is 31.81 million m^3 (total storage), 31.28 million m^3 (effective storage) and 0.53 million m^3 (dead storage) with sediment volume of 11.66 million m^3 (dead storage) and 18.83 million m^3 (effective storage). The sedimentation rate of the Selorejo reservoir is contributed from 3 (three) rivers it contains, including the Konto river, the Kwayangan river and the Pinjal river. The trap efficiency of the Selorejo reservoir shows a declining trend in proportion to the reduction in reservoir storage capacity with a value in 2019 of 86.66%. The average sedimentation rate of 0.622 million m^3/year. Based on the existing sedimentation conditions assuming the dredging volume is in accordance with the average sediment dredging that has been carried out, it is known that the service life of the Selorejo reservoir is 54.43 years or up to 2023.

Considering the volume of reservoir sediment control and resources in sediment control, among others: dredging capastity and available spoilbank storage and capacity and condition of sediment control structures upstream and downstream of the reservoir, a proposed sediment control method with a combination of reservoir sediment dredging methods, sabo dam dredging and making check dams in 5 (five) alternative sediment control.

TABLE 6. Alternative matrix sediment control and costs incurred per year

Alt.	Sediment control volume (m^3)	Sediment Control Methode						Cost (Rp)	Information
		Dredging reseroir sediment				Dredging sabo dam deposit sediment	Check dam construction		
		Sp.bank volume by exaltation existing s.b. (m^3)	New sp.bank volume (m^3)	Sp.bank volume by hauling existing s.b. (m^3)	Riverine disposal (down stream) volume (m^3)	Sediment volume (m^3)	Sediment volume accommo-dated (m^3)		
1	215.000	130.000		85.000				15.870.000.000	
2	430.000	130.000	250.000	85.000				37.020.000.000	
3	430.000	130.000	250.000		85.000	50.000		36.120.000.000	Dredging in *sabo dam* di Mendalan S.D.
4	430.000	130.000	250.000				50.000	42.420.000.000	
5	430.000	130.000	250.000			50.000		34.270.000.000	Dredging in *sabo dam* di Tokol S.D.

From the calculation of the value of benefits and the addition of reservoir service life in each alternative, the following results are obtained:

a. The value of the benefits of alternative sediment control 1 is IDR 160,644,115,316 with an additional service age of 5.62 years.
b. The value of the benefits of alternative sediment control 2, 3, 4 and 5 were IDR 282,781,322,778 respectively, with an additional service life of 11.92 years, respectively.

Alternative 1 has the highest level of efficiency but is only able to increase the service life of the reservoir for 5.62 years and alternative 2 has the level of efficiency in the second rank by increasing the service life of the reservoir for 11.92 years.

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REFERENCES

[1] C. Asdak, *Hidrologi dan Pengelolaan Daerah Aliran Sungai*, 3rd ed. Yogyakarta: Gadjah Mada University Press, 2004.
[2] H.W. Hudson, *Soil Conservation*, London: BT. Batsford Limited, 1971.
[3] Analisis-Regresi, by Rufi'i Adibuana., 2012.
[4] Anonymous, *Pedoman Konstruksi dan Bangunan Sipil Survey dan Monitoring Sedimentasi Waduk*, Jakarta: Departemen Pekerjaan Umum Direktorat Jenderal Sumber Daya Air, 2009.
[5] Soewarno, *Hidrologi, Pengukuran dan Pengolahan data Aliran Sungai (Hidrometri)*, Indonesia: Penerbit Nova, 1991.
[6] Morris, Gregory L., and Fan. Jiahua, *Reservoir Sedimentation Handbook*. NewYork: McGraw-Hill, 1998.
[7] Anonymous, *Pedoman Konstruksi dan Bangunan Sipil Survey dan Monitoring Sedimentasi Waduk*, Jakarta: Departemen Pekerjaan Umum Direktorat Jenderal Sumber Daya Air, 2009.
[8] Zerbe Jr., Richard, and Bellas, Allen S., *A Primer for Benefit-Cost Analysis*, Cheltenham: Edward Elgar Publishing Ltd, 2006.
[9] Widhie Arzy Restuanti, "*Analisis Perhitungan Biaya Operasi Dan Pemeliharaan Irigasi Untuk Mewujudkan Biaya Jasa Pengelolaan Sumber Daya Air Pada Daerah Irigasi Delta Brantas",* Thesis. Surabaya: Institut Teknologi Sepuluh Nopember, 2016.
[10] Anonymous, *Final Report on Strengthening of The Operation and Maintenance System for PJT I*,Volume VII Data Book IV, Indonesia : Nippon Koei Co., Ltd., 2007.